

LA-UR--83-1209

DE83 011176

(1)

Conf-831016--1

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

TITLE: PASSIVE-SOLAR-HEATING ANALYSIS: A NEW ASHRAE MANUAL

AUTHOR(S): J. Douglas Balcomb

SUBMITTED TO: Solar 83 International Solar Energy Symposium
Palma de Mallorca
October 2-6, 1983

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy

MASTER

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

PASSIVE SOLAR HEATING ANALYSIS, A NEW ASHRAE MANUAL*

by

J. Douglas Balcomb
Los Alamos National Laboratory
Los Alamos, New Mexico 87545 USA

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ABSTRACT

The forthcoming ASHRAE book, Passive Solar Heating Analysis, is described. ASHRAE approval procedures are discussed. An overview of the contents is given. The development of the solar load ratio correlations is described, and the applicability of the analysis method is discussed.

INTRODUCTION

Several years of work at the Los Alamos National Laboratory have led to a new book, Passive Solar Heating Analysis, to be published by ASHRAE. This book incorporates information previously presented in Volumes Two and Three of the Passive Solar Design Handbook [1,2], plus some new information especially prepared for the book. The analysis procedures are based on use of the Los Alamos solar load ratio (SLR) method.

To achieve a consistent and smooth presentation of the material in a manner that makes it easy to use, Volumes Two and Three have been completely

*This work performed under the auspices of the US Department of Energy, Office of Solar Heat Technologies.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

EJB

rewritten by a technical editor. The purpose of this paper is to outline the approach taken, to give a brief summary of the book, and to discuss the applicability of the analysis techniques.

ASHRAE APPROVAL

ASHRAE appointed a subcommittee, especially for the purpose of overseeing the development of the book, consisting of the following people:

Chairman: Bruce Novell, Alabama Solar Energy Center
Steve Heibin, Innovative Design, Inc., and
Benjamin T. Rogers, Consulting Engineer

The subcommittee was appointed by Stanley Mumma, Chairman of ASHRAE Committee 6.7 on Solar Energy Utilization, and was directed to scrutinize very carefully the contents of Passive Solar Heating Analysis to assure that it is in conformance with ASHRAE standards and requirements.

The subcommittee worked very closely with the Los Alamos authors and the technical editor, reviewing earlier drafts and making many suggestions. In addition, several other ASHRAE members reviewed the second draft. The final draft is to be submitted to the entire Solar Applications Committee for their formal review and approval. Pending approval of this committee, and other higher-level ASHRAE committees, the book will be published in late 1983. At the time of this writing (April 1983) the second complete draft has been reviewed and approved by the subcommittee, and work on the final review draft is well along.

OVERVIEW OF THE CONTENTS

The book is intended to fit smoothly into the passive solar design process, providing quantitative bench marks during schematic design and design development to provide assurance that the energy consumption goals of the project will be met. To this end, the book is divided into two parts, oriented respectively to (1) techniques useful during schematic design, and (2) design development.

Part One, Analysis for Schematic Design

The first chapter introduces the procedures and presents the nomenclature. The second chapter of Part One presents design guidelines. Thirty guidelines are given; these are of particular value at the end of the programming phase of design just before the beginning of schematic design. The first two guidelines give recommended values of wall insulation, ceiling insulation, and other conservation levels, and a recommended value of total passive solar collection area. Tables provide specific guidance for 209 locations in the US and 10 locations in southern Canada. The guidelines are based on balancing conservation and solar based on relative performance and costs. Figure 1 shows the annual solar savings fraction (SSF) that would result from using the guidelines assuming that the passive system selected is a sunspace. Additional general guidelines pertain to orientation, tilt, and other factors.

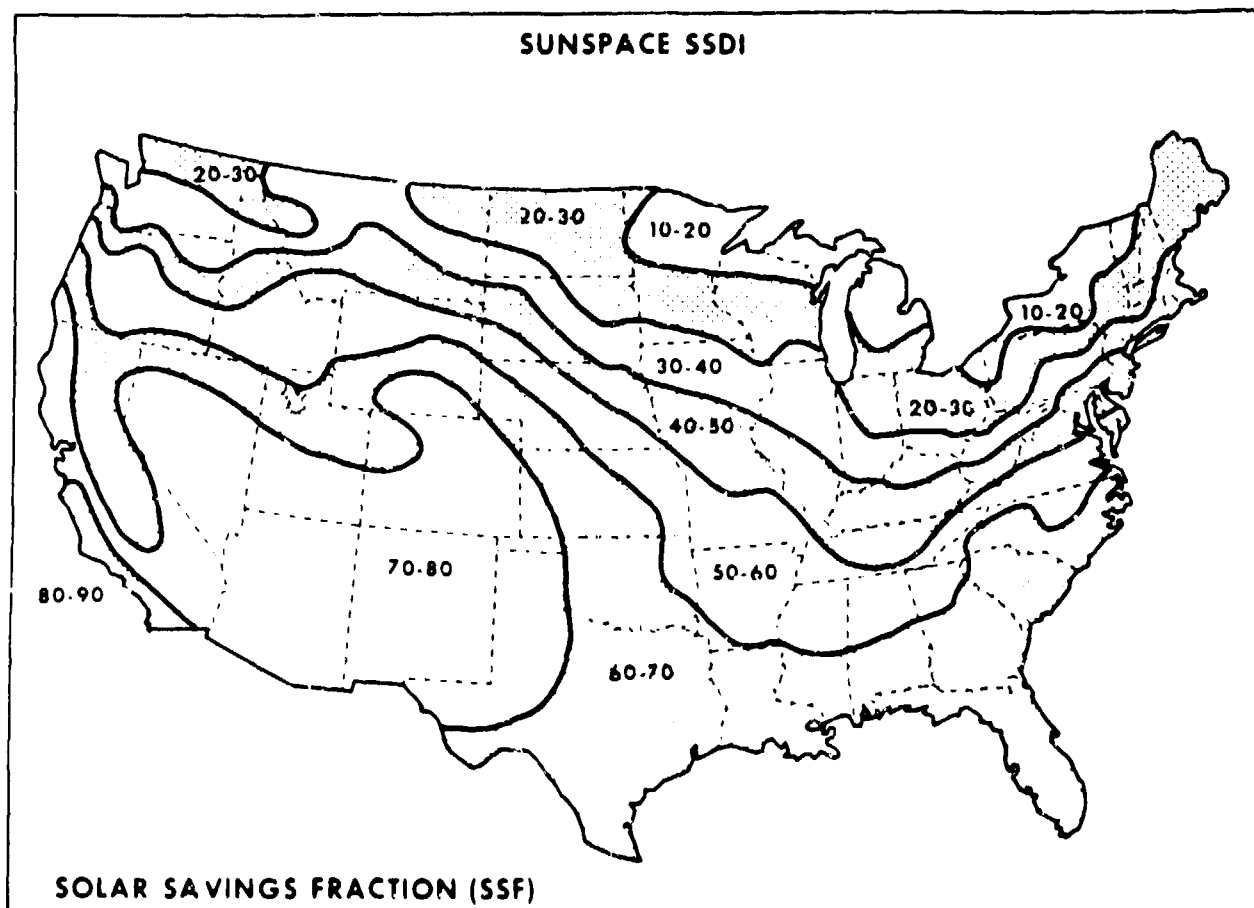


Fig. 1. Solar savings fraction, in per cent, for sunspace system SSD1 (semienclosed, 50° slope, opaque end walls, double glazing, masonry common wall, no night insulation), assuming that the system has been sized in accordance with the recommended design guidelines.

The remaining guidelines relate to particular system types: direct gain, sunspace, and thermal storage walls (Trombe walls and water walls). Guidance is given for thermal-storage thickness, deployment, and color, as well as specific recommendations on aspects such as vents in Trombe walls and use of selective surfaces.

Chapters 3, 4, and 5 present the annual method, sometimes called the year-as-a-whole method. Simplified procedures are introduced for estimating the building net load coefficient and modified degree day base, accounting for the effect of internal heat. The performance of the passive solar system can then be estimated using SSF tables prepared for 223 cities for each of 94 different reference design options. These tables, although voluminous, provide a very quick estimate of SSF. The performance of mixed designs can be determined using an appropriate average of the SSF values of each of the passive systems used. Average winter clear-day temperature and temperature swing can also be estimated.

Sensitivity data can be used to determine the effect of differences between the values of design parameters and those of the reference designs for which the correlations have been made. Although these sensitivity data are given in Part Two, they are equally applicable to the annual-method results.

The proper balancing of conservation and solar aspects of the building is the subject of the next chapter. The optimum mix of conservation and solar depends on the temperature and solar radiation data of the site, the performance characteristics of the passive system, and the relative incremental costs of the conservation and solar strategies. The performance side of this relationship is characterized by a single parameter, called the conservation factor, which is tabulated for the same systems and cities as the SSF tables. From knowledge of the incremental costs of adding insulation and adding passive solar collection area, the designer can determine the economic optimum conservation level and passive-system size. The design can be adjusted, as appropriate, either to fit within a total construction budget or to attain a life-cycle optimum, considering the estimated present value of the future cost of auxiliary heating energy.

Part One concludes with a series of examples together with filled-in worksheets to facilitate the procedures.

Part Two, Analysis for Design Development

Part Two presents the monthly SLR method, sometimes called the month-by-month method. This procedure provides additional flexibility, compared with the annual method, but is considerably more time consuming. Thus, it is recommended for this later phase of the design process.

The two principal advantages of performing a monthly calculation after having done the annual method are as follows:

1. Insight is obtained into the month-by-month behavior of the system, and
2. There is complete flexibility in adjusting the monthly values of solar energy absorbed by the building.

The most difficult aspect of the monthly method occurs in the estimation of solar gains, and an entire chapter is devoted to this calculation. For each glazing orientation and tilt, monthly values of incident solar radiation, transmission through the glazing, and fraction absorbed by the building can be estimated. Incident solar radiation is estimated by multiplying the measured average daily horizontal solar radiation by a factor. This factor and the monthly average solar transmittance of the glazing are each estimated using correlations that have been developed for a wide variety of US climates.

The solar radiation correlations are given in terms of two correlating parameters: the monthly average clearness ratio (the ratio of actual horizontal solar radiation to extraterrestrial horizontal radiation), and the noon zenith angle at midmonth. Polynomial coefficients are chosen that minimize the mean square error between the monthly correlations and monthly summaries of hour-by-hour calculations. Use of these correlations is greatly facilitated by providing values of both clearness ratio and zenith angle in the weather and

solar data tables for each city, and also by providing graphs showing the dependence of each factor on these parameters. The polynomial coefficients are provided for those who might be working with a microcomputer. Solar radiation correlations are presented for each 30° increment of both orientation and tilt; worksheets are provided to facilitate the calculations.

The performance of each of the 94 passive system types can be characterized in terms of a set of SLR correlation constants and values of the monthly ratio of solar radiation absorbed by the building to monthly heating degree days. Calculations for mixed systems are done in a manner analogous to the annual method.

Part Two includes three chapters that discuss the individual characteristics of direct gain, sunspace, and thermal storage wall (Trombe wall and water wall) passive solar systems. Sensitivity curves are given showing the effect of changes in selected reference design parameters together with discussions of the important performance characteristics of each. Figure 2 shows a typical sensitivity curve. Part Two concludes with a chapter of worked examples.

Appendices

A major part of the book is dedicated to appendices. These provide critical information necessary for carrying out the various calculations. All of the correlation constants and a detailed description of the design parameters are included for each of the 94 reference designs. Weather and solar data tables

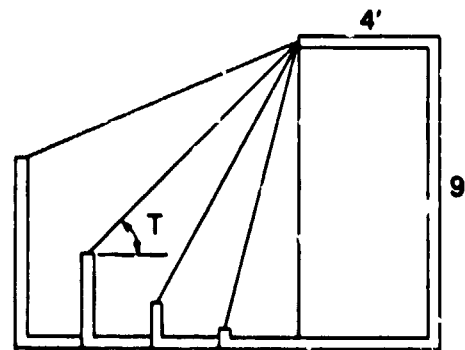
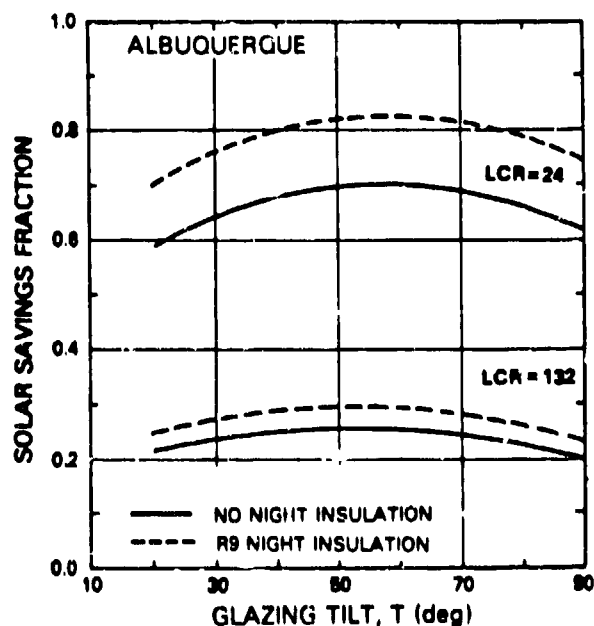


Fig. 2. Annual heating performance sensitivity to the sunspace glazing tilt in the case of a masonry-common-wall, insulated-end-wall configuration with a single tilted glazing plane. The glazing area is held constant as the tilt is varied by the addition of a variable height knee wall. The drawing below illustrates the geometry.

give solar radiation, heating degree days to several bases, and other needed data for each month, for 223 cities located in the US and southern Canada. The largest table in the appendix provides annual SSF values for each of the reference designs for each of the cities for 8 values of load collector ratio (LCR) and 2 values of base temperature, 65°F (18.3°C) and 55°F (12.8°C). It is this table that allows annual method calculations to be done quickly during schematic design. The table has been generated by performing month-by-month SLR calculations for each of the 335392 cases listed and tabulating the resulting SSFs. Similar calculations are done to obtain the conservation factor.

The book is written entirely in British units; however, constants are given to convert the results into various metric unit systems.

DEVELOPMENT OF THE CORRELATIONS

The SLR correlations have been developed based on hour-by-hour computer simulations of each passive solar system in a selection of US cities having a very broad range of climate characteristics. The computer program used is the PASOLE (PASSive SOLar Energy) thermal-network-simulation program developed by McFarland[3]. The program has been validated by comparison with test-room results. A thermal-network representation of each of the reference designs is generated, and the program is run for one complete year using Typical Meteorological Year weather data. This process is repeated for each of the cities for five values of solar collection area, and the results are summarized in a monthly data file. The correlation consists of an assumed exponential dependence of monthly solar savings fraction upon the correlating parameter, the SLR. This dimensionless ratio relates the monthly solar energy absorbed by the building to the monthly heating energy requirement. Several constants that appear in the functional form are adjusted to obtain a minimum square error in the annual solar savings fraction averaged over the entire ensemble of data from all cities. The resulting mean square error in SSF varies somewhat from system to system, but is typically 4%. This is comparable to the observed error in prediction of auxiliary heat when comparing the results of simulation analysis with passive solar test-room results. Further detail on the development of the SLR correlations is given in Ref. 4.

APPLICABILITY

To generate an SLR correlation, numerous assumptions were made in the reference design characteristics. These include design parameters of the passive system (such as the thickness of the Trombe wall, glazing properties, and ground reflectance) and the operating characteristics of the system (such as the 41.9°F [5.5°C] indoor temperature range allowed, and the day/night operation of vents). Strictly speaking, the correlations are only applicable to buildings that match these assumptions. However, there are a large number of correlations that provide a wide choice of geometries. Furthermore, the sensitivity curves can be used to determine the effect of variations in certain parameters or combinations of parameters.

Most SLR correlations are based on adequate thermal mass in the building. The methods are not recommended for situations where there is too little heat

storage. This is not to imply that the SLR method cannot be used for timber-frame buildings or other lightweight construction. The mass in such buildings may be adequate for a direct gain south window area equaling 7 to 10% of the floor area. Problems tend to arise when the direct gain percentage exceeds this by very much. Overheating will occur, causing discomfort; occupants will open windows in midwinter, with a resultant decrease in performance. It is recommended that either internal mass walls be added or that a Trombe wall or sunspace be used to extend the glazed area and thereby increase solar savings.

The analysis methods implicitly contain the assumption that the scheduling of equipment is uniform throughout the day and night. There is no thermostat setback. Equipment, such as lights and appliances, generates heat at a constant rate. It is unlikely that these conditions would be exactly satisfied in a given application, but the long response time of a well-designed passive solar building reduces the effect of time-dependent scheduling. Many cases can be accurately analyzed by ignoring thermostat setback and by assuming that the internal heat is generated at a constant rate. In other cases, however, this is a poor assumption, e.g., a building with intermittent use and large occupancy loads.

Questions often arise about the applicability of the SLR techniques to commercial buildings. No general statements can be made here; in some cases the method will be applicable and in others it will not. Many commercial buildings have large internal gains that offset the need for other heat. Using a modified degree day base allows the user to account for the effect of this internal heat. Some commercial buildings have several separate zones; however, in many commercial buildings, an air-handling system is installed to distribute air continuously throughout the building. This has the effect of creating a constant temperature throughout the building, thus satisfying one of the important assumptions on which the correlations are based. If this is not the case, SLR methods can be applied on a zone-by-zone basis. However, in many commercial buildings the heating, ventilating, and air-conditioning equipment introduces thermal interactions between zones and between the equipment and the passive systems. Such interactions can either be detrimental or advantageous to the overall building energy performance, but in any case, care must be exercised before applying the methods.

The SLR method provides an estimate of the auxiliary heat only. Because heating is often not the principal thermal design issue in commercial buildings, SLR is only one tool. Other methods for estimating cooling needs should be used to complement SLR in an overall thermal-design process. Commercial buildings where heating and cooling systems are operated simultaneously should be analyzed by methods that account for time-of-day and building zoning. The relationship between the occupancy schedule and the timing of heat delivery must also be considered.

Daylighting is also an important energy-design issue in commercial buildings. As windows are added to achieve daylighting, the heating requirements are increased, shifting the building toward a more skin-dominated situation and making it appropriate to use the windows for their added passive solar gain to meet the heating load. SLR provides the needed tool to estimate the solar savings achieved.

Summer heat avoidance is a concern to any designer, particularly in regions of summer overheating. Many design strategies are available for shading the aperture, which is essential; good ventilation is also essential, especially for sunspace situations. The added mass in a good passive solar design aids in summer temperature stability, which may allow the building to coast comfortably through high afternoon temperatures and take advantage of cool night temperatures during seasons when they occur.

The designer may well want to use more comprehensive (and complex) calculation tools, such as computer programs, with which one can perform hour-by-hour simulations of building performance. This will produce a more complete picture than SLR and may be warranted for certain complex designs or difficult climate situations. However, even when a designer chooses to use complex calculation tools, SLR provides a quick first step in the design process.

USE WITH MICROCOMPUTERS

The SLR techniques described in the book have been incorporated into micro-computer programs by several different programmers. Some of these are available for sale specifically for the more popular desktop systems such as Apple® and Radio Shack® computers. The routines are very fast and offer the designer a simple and immediate way of assessing the effect of changing various design parameters.

CONCLUSION

Passive Solar Heating Analysis provides a specialized and convenient tool to assist the designer of passive solar heated buildings. By choosing the proper analysis procedure at different points in the design process, the designer can intelligently choose conservation levels and passive solar heating features from the very beginning and conclude with an accurate estimate of the building heating performance.

ACKNOWLEDGMENTS

The co-authors of Passive Solar Heating Analysis are J. Douglas Balcomb, Robert W. Jones, Robert D. McFarland, and William O. Wray of the Los Alamos National Laboratory. The technical editor is Edward Nelson of Tech Reps, Inc. Contributing authors are Dennis Barley, Claudia Kosiewicz, Gloria Lazarus, and Joseph Perry, Jr. of the Los Alamos National Laboratory.

REFERENCES

1. J. D. Balcomb, C. D. Barley, R. D. McFarland, J. E. Perry, Jr., W. O. Wray, and S. Noll, Passive Solar Design Handbook Vol. II, US Department of Energy report DOE/CS-0127/2 (January 1980).
2. J. D. Balcomb, C. E. Kosiewicz, G. S. Lazarus, R. D. McFarland, and W. O. Wray, Passive Solar Design Handbook Volume III, R. W. Jones, Ed., US Department of Energy report DOE/CS-0127/3 (July 1982).

3. R. D. McFarland, "PASOLE: A General Simulation Program for Passive Solar Energy," Los Alamos National Laboratory report LA-7433-MS.
4. J. D. Balcomb, R. W. Jones, R. D. McFarland, and W. O. Wray, "Performance Prediction of Passive Solar Heated Buildings by the Solar Load Ratio Method," Passive Solar Journal 2, Spring 1982. (LA-UR-82-670 Revised)